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Upgrade of the DRDC Suffield Blast Tube Facility

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Contract Scientific Authority: Y. Das, DRDC Suffield

Defence R&D Canada

Contract Report

DRDC Suffield CR 2009-018

December 2007

Canada

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Contract Report
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Upgrade of the DRDC Suffield Blast Tube Facility

DRDC-Suffield 1.8m FAE Blast Tube prior to Bldg. 148 enclosure

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EXECUTIVE SUMMARY

Upgrade proposals are presented for the DRDC Suffield Blast Tube facility designed to extend its testing range and capabilities for conducting studies of structural response and injury from blast. By means of straightforward modifications, the facility's operational Pressure-Impulse (P-I) envelope can be greatly extended as well as its capacity to test full-scale responding targets. Blast conditions equivalent to those from charges of several kilograms of high-explosive to small tactical nuclear devices (0.25KT) can be simulated. This extended capability can be achieved by the following modifications which can be implemented independently in phases if necessary:

- Installation of an optional breech insert for condensed low-explosive (LE) charges such as black powder and some classes of propellant or thermobaric explosive. Such charges produce much stronger blast at lower durations than the current FAE driver, yet do not have the storage/handling difficulties or damage potential to the current driver as HE charges.
- Installation of a relocatable test table which will allow testing of $0.25m^2$ diffraction targets at conditions simulating those near the edge of an HE fireball (1MPa x 5ms) to low amplitude deflagration events (10kPa x 100ms)
- Construction of an extension/expansion section for the current end of the Tube having a reaction-frame foundation to allow mounting of full-scale structural wall/panel segments 2.5m-square, debris projection and blast ingress effects within room enclosures.
- Refurbishment of the current main 30m Test Station including activation of the 'clam-shell' access and resurfacing of the test table for improved target mounting.
- Upgrade and refurbishment of the current FAE fuel-flow control and firing system, including the redesign of the fuel dispersal rig of the current FAE driver to allow its extraction for staging of LE firings.

Advanced conceptual designs for the upgrades are presented, and the efficacy of the proposals in extending the P-I range is demonstrated by blast CFD modeling. For each upgrade proposal, a more detailed engineering study will be required prior to proceeding with fabrication or re-construction; sub-scale shock-tube testing and more detailed computational modelling should be applied for this purpose. The upgraded facility offers much lower cost, higher reproducibility and control of variables, higher safety, and freer scheduling than explosive field trials. The capabilities offered by this facility will be unique in Canada and amongst the most efficient for this scale of testing in the world.

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1. Introduction

Apart from computational modeling and a very limited range of analytical calculation methods, experimental test capabilities are the foundation for any credible R&D program in blast vulnerability and remain the ultimate method for validating blast protection technologies. Experimental capabilities generally fall into two categories: free-field trials and blast simulator facilities. Free-field explosive trials require large, specially designated test ranges demanding considerable personnel and logistical resources. Costs, scheduling, repeatability, and control or monitoring of target boundary conditions are also problematic. Adverse weather conditions alone are a predominant impediment. Although field trials offer the only means to test complete large-scale responding structures, in reality most blast vulnerability problems can be reduced to assessment of a key component or localized configurations such as walls, doorways, or windows. A good example of blast qualification testing of a critical sub-structure component is the US GSA Blast Testing protocol for qualifying window blast resistance [1]. For systematic experimental studies of blast phenomenology, loading, damage, and personal injury, field trials are exceedingly expensive and inefficient.

Blast Tubes are shock tubes specially designed to simulate the particular shock-wave flow profiles produced by free-field explosions. It is important to note that standard shock tubes, especially those driven by compressed gas, do not inherently generate the gas-dynamic flow profiles representative of free-field blasts. Such facilities will yield deceptive results for blast effects unless carefully designed and unless targets are staged at proper test stations. A quadripartite research symposium, “Military Applications of Blast Simulation”[1], was formed in the mid-1960s for the sole purpose of designing blast simulators to produce the specially tailored waveforms representative of nuclear blasts.

The 1.8m FAE Blast Tube at DRDC Suffield is one of the most efficient and high-performance blast test facilities of its size in the world for its original purpose to simulate tactical scale nuclear blast-wave profiles. Incident blasts of nearly 300kPa and 120ms duration can be generated at the main test station. The facility does not require a diaphragm and uses remotely controlled flowing and firing of fuel-air explosive gases to generate the explosion in the driver chamber; it can be safely operated with as few as two personnel including baseline instrumentation recording. Being explosively driven, the Tube inherently produces many of the key features of free-field blast waves. As described in Ref. 2, there are only a few large-scale blast simulators of this capability world-wide. Most are one-of-a-kind facilities due the particular era, budget, location, available technology, or other circumstances of their development. Historically, such facilities were developed by national Defence departments to study effects of nuclear-scale blasts having long durations (100-1000ms) and moderate amplitudes (20-200kPa) for which they are intrinsically well-suited to simulate as will be described. Private contractors in the area of risk assessment and Universities have also developed test facilities of this type for studies of industrial blast accidents and protection technology.

[1] The first symposium was hosted in 1967 by Suffield Experimental Station, now DRDC Suffield. (See http://www.mabs.ch/). Having developed a broader scope covering all aspects of experimental and computational blast research, MABS was renamed in the 1990’s to “Military Aspects of Blast and Shock’.

Current research priorities for DRDC blast studies have shifted from the previous focus on nuclear-scale blast to new threats, such as close-in blast damage and injury, that would be inflicted by terrorist bombings against military, civilian infrastructure, and industrial targets using both conventional and non-conventional explosive materials. Protection against roadside Improvised Explosive Devices (IEDs) currently inflicting serious casualties and vehicle damage to Canadian Forces in Afghanistan is of particular interest. Industrial as well as ammunition storage blast accidents also call for a wider range of blast profiles which can be generated and target types and protection concepts that can be tested. In addition, far better capability is required to test full-scale responding structural components or systems as well as anthropomorphic manikins and their components.

2. Overview Description of Current Facility

A photograph of the Blast Tube itself prior to its enclosure is shown in Fig. 1 as well as a more recent aerial view showing the enclosures by Bldg. 148 and the driver shelter. The site is located at E924 N646 on DRDC Experimental Proving Ground, about 10kms SE by road from the Main Base and about 1km N from Gate S20.

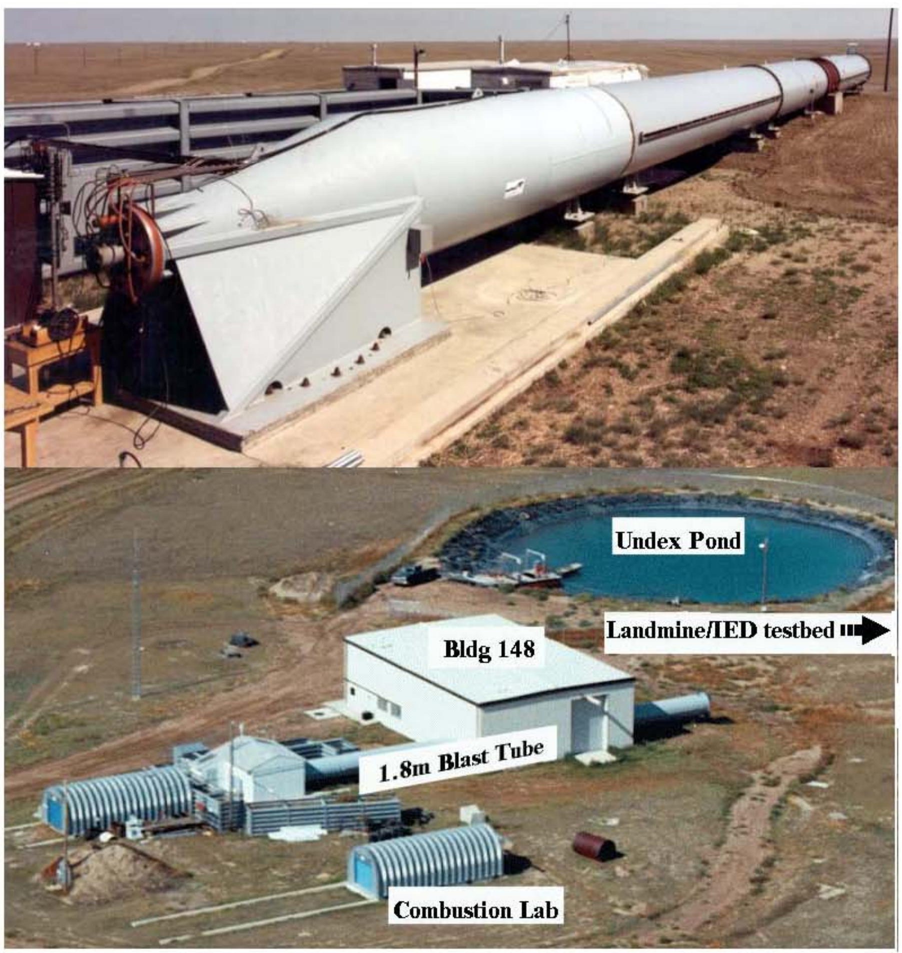

Figure 1. Photographs of the DRDC Suffield FAE Blast Tube and site layout.

A detailed description of the Blast Tube and its operation are provided in Ref. 3 but will be summarized here for completeness. As shown in Fig. 1, the Tube is comprised of a conical ‘driver’ section of heavy-wall steel 2.6m in length connected to a straight tubular main test section of 44.6m length and 1.8m internal diameter. The truncated apex of the conical driver has a 0.46m-diameter opening into which a special breech plug is mounted for the gaseous fuel filling system. The complete breech-end assembly accommodates the breech plug as well as an annular array of remotely controlled venting ports to purge detonation gases post-shot. The firing of the Blast Tube is unique in that the main charge is an unconfined ethylene-air cloud detonated by a small oxy-acetylene booster balloon at the apex of the conical driver which in turn is initiated by a simple electrical spark discharge. Therefore the entire filling, firing, and purging operation can be conducted remotely with as few as two personnel, with both high safety and very prompt turn-around times. Well-defined and highly reproducible blast waveforms are produced.

Blast testing is divided between *diffraction* and *full-reflection* target types. Diffraction targets are typically smaller structures mounted within the Tube such that the blast fully diffracts and envelops the structure in 3-dimensions. As with wind-tunnel testing in aerodynamics it is important that the structure not greatly obstruct the cross-sectional area causing flow confinement and reflections adversely affecting the intended free-field response. The cross-sectional blockage should not exceed 10% or about 0.25m^2. Diffraction targets are currently mounted at the primary test station table, 30m from the driver. ‘Full-reflection’ targets are 2D panel or wall structures mounted to block the end of the Tube and are hence subjected to uniform normal reflection blast loading. Examples of current blast waveforms at the Test Table, a typical diffraction target setup, and reflection target setup are shown in Fig. 2.

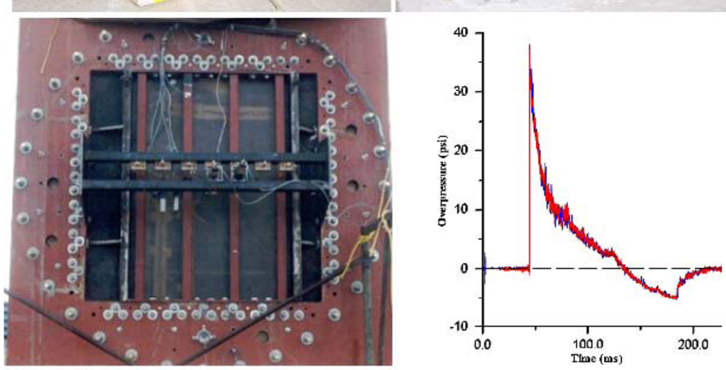

Figure 2. [Upper left to right] model scale tent target, damage to wire frame, and comparison with full-scale trial damage. [Lower left] Instrumented GRP panel target mounted to the end-flange of the Blast Tube. [Lower right] Typical overlay of blast waveforms at 30m test station.

3. Current Blast Tube Performance

3.1 *Characterizing Blast Simulator Performance*

The classical blast waveform for a free-field high-explosive (HE) spherical explosion is depicted in Fig. 3 which also shows the decay of the key parameters of peak pressure *P* and impulse *I* with distance in the free-field in terms of energy scaling. In simplest terms the goal of any blast-simulation facility is to generate realistic blast waveforms for the widest range of P-I conditions of interest as well as to have the capacity to properly mount target structures and extract data. Ideally, the facility should allow means to adjust wave-shape, including features such as the negative phase and secondary shock as shown in Fig. 3, as well as *independently* adjust peak overpressure and impulse. The performance of a blast test facility is best described in terms of the P-I or P-Δt range for the facility, that is, in terms of peak static pressure *vs* impulse, or peak static pressure *vs* duration. By this means it is possible to quickly match the Tube performance against its 'equivalent' HE event.

An important remark on the performance of a blast simulator facility is the necessity to reproduce all the time-variant gas-dynamic conditions of free-field blast such as density and flow velocity, not only static pressure which is the standard reference parameter. As described in Ref. 4, it has been disturbingly common in recent research involving blast simulation to presume that a particular profile of static pressure measured in such a facility implies that all gas-dynamic conditions match free-field blast as required. In fact this is by no means true in general, the most likely deviation being in concurrent matching of static and dynamic pressure profiles. However, those issues of blast simulator inconsistencies with free-field blast will not be expounded here since in fact the DRDC Blast Tube has been configured correctly.

This approach to characterize blast simulator performance with P-I or P-Δt diagrams is analogous to the methodology used in blast structural response science whereby a structure's vulnerability to blast is depicted by means of a pressure-impulse (P-I) iso-response diagram [5,6]. It is also the classical basis for depicting human vulnerability to blast as in the Bowen curves which use the incident blast P-Δt conditions to chart human vulnerability to blast [7]. These methodologies to map or depict target vulnerability are important to discuss here since the goal of blast simulation facility is to offer as continuous and independent variation of P and I or Δt parameters as possible in order to experimentally map a target's full domain of blast response.

P-I diagrams chart target response using a key response indicator (such as peak deflection of a wall for example) as a function of the two primary load parameters, peak overpressure and positive-phase impulse. Dependent on the particular derivation or user requirement, the diagram may be presented as a function of either the incident or loading P-I conditions. Using a selected response criterion such as deflection at a key location, it is possible to graph 'iso-damage' curves which define the combination of P and I conditions which inflict the same response. The iso-damage contour for the critical response criterion, such as a maximal allowed deflection, defines the domains between "failure" and "survive". As shown in Fig. 4, P-I diagrams allow a very simple graphical

depiction of target vulnerability: blast conditions above the curve cause 'failure', conditions below the curve are 'survivable'. P-I diagrams can be generated using analytical or computational models, in the simplest method using the Single-Degree-Of-Freedom (SDOF) technique. Experimentally, P-I diagrams can be generated by systematically varying peak overpressure and impulse of the blast conditions and monitoring target response.

Standard shock tubes, blast tubes, or blast tunnels, even when explosively driven, do not inherently generate shock-wave flow conditions representative of free-field explosive blasts as depicted in the 'classical' time record for TNT blast as shown in Fig. 3. Therefore, without careful design such facilities intended to qualify or calibrate structural systems or personnel protection against blast threats will not have the required performance P-I envelop and in fact may generate invalid or deceptive shock-wave conditions.

Although there is a conical driver section to the DRDC Blast Tube, as with most such facilities the shock-wave propagation down the length of the Tube is effectively 'quasi-planar' due to having constant cross-sectional area. The important result of this difference in blast expansion compared to free-field explosions is that in general the signature will not develop a distinct negative phase or secondary shock. These features arise in free-field air-blasts due to the inherent cylindrical or spherical expansion geometry of the charge shape, and can be important for some structural response studies including window-breakage [8, 9]. For very small driver charges, up to few hundred grams HE-equivalent, a negative phase and secondary shock will develop in the DRDC Blast Tube. As a rough guide, if the extent of the fireball expansion is less than half the length of the conical driver, a full free-field profile with negative phase will be generated.

An important outcome of the blast propagation in this geometry is that the blast strength decays far less rapidly with distance than in the free-field, roughly $\sim x^{-0.7}$ where x is distance down the Tube scaled to initial explosive energy per unit cross-sectional area. Secondly, the waveform becomes extended in duration at a faster rate relative to free-field blast propagation. An artifact of the competing effects of the slow decay of amplitude and the expanding duration is that for a given driver charge, the impulse in blast tubes is roughly constant as a function of distance [10, 11]. This characteristic has some advantage in that simple relocation of a target along the length of the Tube allows mapping of a P-response profile at constant 'I' for the P-I diagram of the structure. However, the use of a relocatable test station alone will generally not be sufficient to assess the whole domain of P-I response without resort to other upgrade modifications. Therefore it is necessary to consider other techniques to allow both a wider range and independent adjustment of P-I parameters.

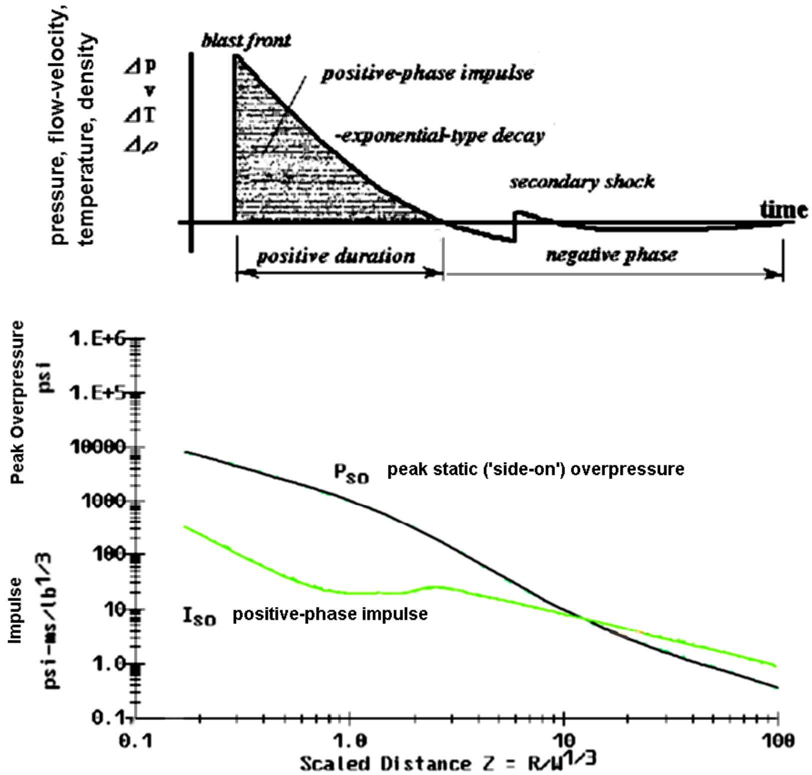

Figure 3. Waveform for a classical high-explosive blast and decay of the key parameters of peak overpressure and impulse with distance in the free-field.

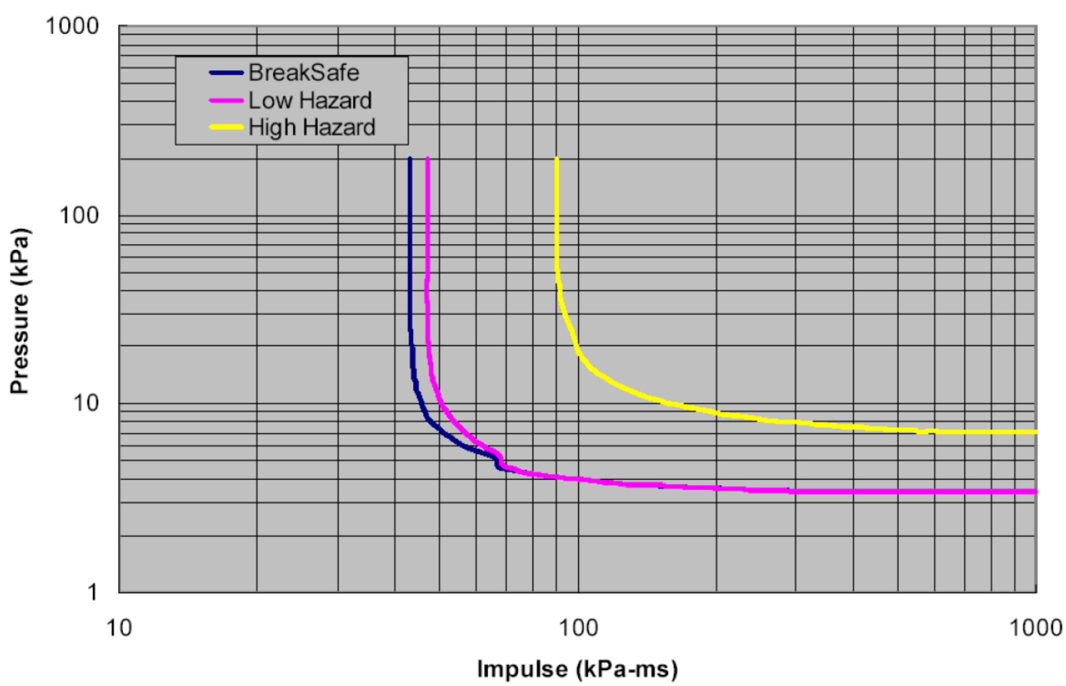

Figure 4. Typical form of P-I diagram in this case for window glass breakage [from "Glazing Hazard Guide", Security Facilities Executive (SAFE), an Agency of the UK Cabinet Office, Office of Public Services, June 1997.]

3.2 *Current Blast Tube Performance*

It is possible to superimpose the range of P-I blast conditions from a particular free-field HE blast with those for a system's P-I blast vulnerability diagram, as well as overlay the performance range from a blast simulator. The approximate performance range for the current Blast Tube facility is shown in Figs. 5 and 6. These two figures distinguish *diffraction* from *full-reflection* targets; the former is mapped as a function of incident conditions, the latter is mapped as a function of reflected loading conditions. Curves for human vulnerability to blast according to various criteria are shown on the graph for diffraction targets since this topic has become of increasing priority due to terrorist and insurgent bombing tactics.

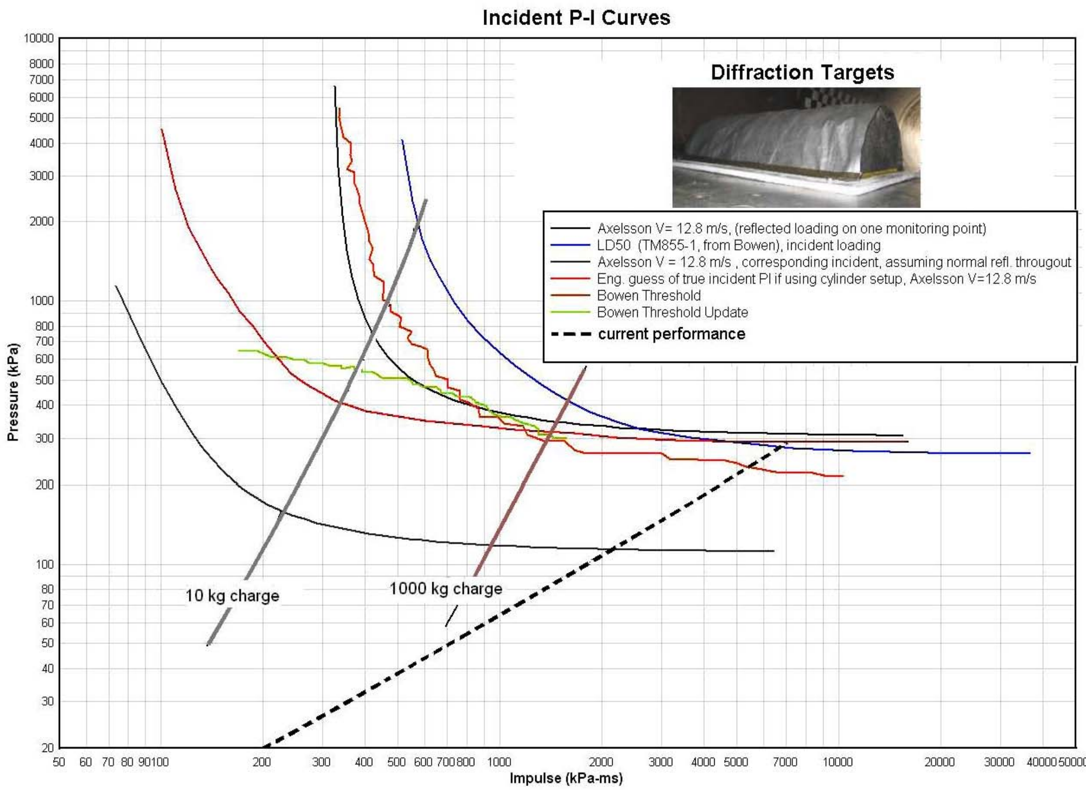

Figure 5. Current performance range of the Blast Tube for diffraction targets highlighting curves for human vulnerability to incident blast conditions based on various criteria.

It is apparent from Fig. 5 that the current Blast Tube produces generally lower overpressures and higher impulses than those required to investigate the most relevant regimes of personal vulnerability. The performance range of the Tube for full-reflection targets is shown in Fig. 6. Although the Blast Tube is capable of producing much higher peak reflected pressure and impulse loading than indicated, the current improvised mounting framework attached to the end-flange of the Tube will not allow testing of target panels to such levels. The resultant forces require construction of a proper robust mounting framework and reaction foundation separate from the Tube itself as will be described.

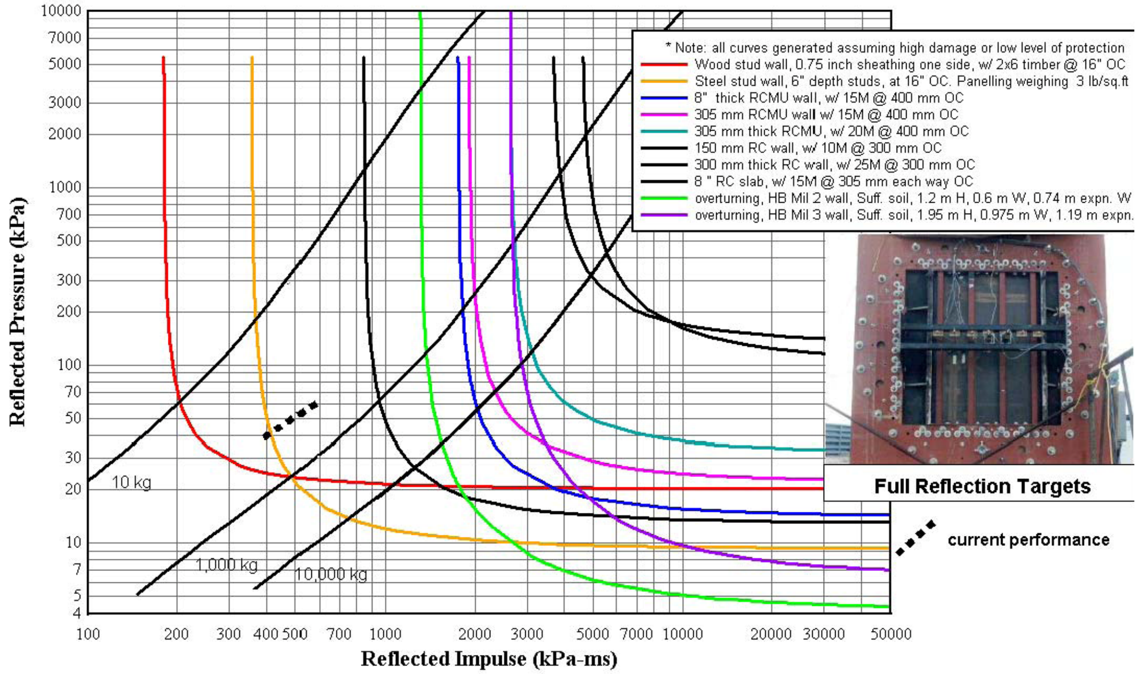

Figure 6. Current performance range for the Blast Tube for full-reflection targets. Although the Tube is capable of producing far higher loading pressures and impulses, the current improvised panel-mounting arrangement attached to the end-flange of the Tube will not withstand the resultant reaction forces.

An important remark about the P-I curves for various structural elements shown in Fig. 6 is that these curves were generated from analyses making many simplifying assumptions; they are shown here for illustration and should not be taken as reference. Indeed, an important role for the upgraded facility would be to validate such curves for key structures, since P-I diagrams are used extensively for quick vulnerability assessments.

The most distinctive feature of the performance ranges for both target types is that these form simple lines in the P-I domain and do not cover *regions*. This is due to the inherent design of the FAE blast generator by which increased blast strength is derived from larger FAE driver charges which also yield longer durations in a prescribed ratio. It is highly desirable that a blast simulator be capable of covering regions of the P-I domain, that is, as much as feasible allow independent and continuous control of peak pressure and impulse as required at the target. Also of note is that the current lower extent of performance is limited by the reliability of achieving a uniform detonation in the smallest charge being a 1m diameter balloon of oxy-acetylene.

4. Upgrade Proposals

Recommended upgrades to the Blast Tube facility to meet the current scope of DRDC blast testing requirements fall into the two categories of “Extending Blast Testing Capability” and “Refurbishments”. Although extended performance attracts obvious attention, the Blast Tube is over 20yrs old and the latter category concerns important modernization of key systems to current standards. These refurbishment or infrastructure upgrades are important for supporting Blast Tube operations as well as allowing more efficient use of personnel time and continued safe conduct of experiments.

4.1 Optional LE Driver Insert

Many current high priority blast vulnerability problems concern protection of structures, vehicles, and personnel from near-field HE blast possibly including impingement of the fireball of detonation products. The high blast intensity, short duration, and gas-dynamic effects from the fireball in this regime cannot be properly simulated by an FAE event. However, the current driver and breech configuration for dispersing and detonating gaseous FAE charges can be made modular and allowed to be extracted and replaced by a simple optional breech plug capable of firing a condensed-phase low-explosive (LE) charge. Low Explosive is defined here as a reactive mixture with a velocity of detonation (VOD) below 1000m/s and covers a broad range of energetic materials including black-powder, propellants, as well as certain pyrotechnics and thermobaric explosives. LE charges are known to largely replicate the blast waveform for HE at sufficient distance,

Figure 7. Current removable breech plug for mounting of FAE initiator balloon.

and the 'shock-up' process is enhanced in the Tube geometry. The advantage of the LE driver is that an effective HE blast can be simulated without the high detonics power which would potentially be damaging to the breech assembly. LE charges also allow safe storage and handling of the primary components under less stringent regulations and operational overhead and expense. Despite these advantages, the capability to run the Blast Tube in 'FAE Mode' is important to be retained.

As shown in Fig. 7, the current breech plug or breech block is designed to be extracted for each FAE firing in order to prepare the oxy-acetylene booster balloon. A substitute breech plug having the same external dimensions and flange attachment but in the form of a simple heavy-wall open-mouth crucible will allow firing of a LE charge as depicted in Fig. 8. A preliminary analysis has verified that a high-strength steel breech as shown will readily withstand a charge of 1kg black-powder equivalent. The safety procedure and qualification of such a breech plug to accept a LE charge will be validated by the DRDC Suffield safety committees in conjunction with qualifying field experiments prior to its deployment in the Tube.

Figure 8. [Left] Cross-section of proposed heavy-wall breech with conical cavity for firing of LE charges. The LE breech block could fit as a substitute with the same fixtures as the current FAE feed plug assembly shown at the right.

In the short term, it has been determined that the breech from the 76mm cannon outfitted for the Cougar vehicle, currently being decommissioned by the CF, can be made to fit with the current breech assembly. As shown in Fig. 9, this breech for the 76mm cannon complete with its firing mechanism is available on-site at DRDC Suffield, and is certified for firing standard 'blank' ammunition having a bag charge of about 700gms of black powder. The blank ammunition cartridges are a CF and NATO stock store item.

Figure 9. Breech for the 76mm cannon certified for firing blank ammunition which can be reconfigured as an interim driver for the Blast Tube.

Various options for configuring a condensed-phase driver charge were investigated by blast CFD modeling including those which would not require a high-strength breech plug. As shown in Fig. 10, the breech plug can be used simply as a means to insert a suspended or cantilevered charge forward into the main conical driver section. In such configurations where the charge itself is not closely confined in a breech, it would in fact be possible to use an HE driver charge such as sensitized nitromethane.

The purpose of the particular CFD modeling study depicted in Fig. 10 was to assess the enhanced range of P-I performance possible with various LE breech configurations as well as identify possible problems such as from transverse wave reflections. Undesirable transverse waves develop from the early radial expansion of the blast at the breech, as well from the later reflection of blast front at the juncture of the conical driver and the main 1.8m Tube section. Transverse wave reflections cause anomalous target loading from the intended 1D incident blast, and in particular due to the cylindrical geometry can cause potentially severe shock focusing at regular intervals along the Tube axis. CFD Results show that similar blast waves of 1MPa peak and 4-5ms duration are produced at the end of the conical driver section for all the LE charge configurations. Although strong transverse reflections are generated early in the blast expansion at the breech, these tend to consolidate with distance. Despite the relatively slight 14° angle of the cone/cylinder junction at 2.6m from the breech, a significant oblique shock reflection is

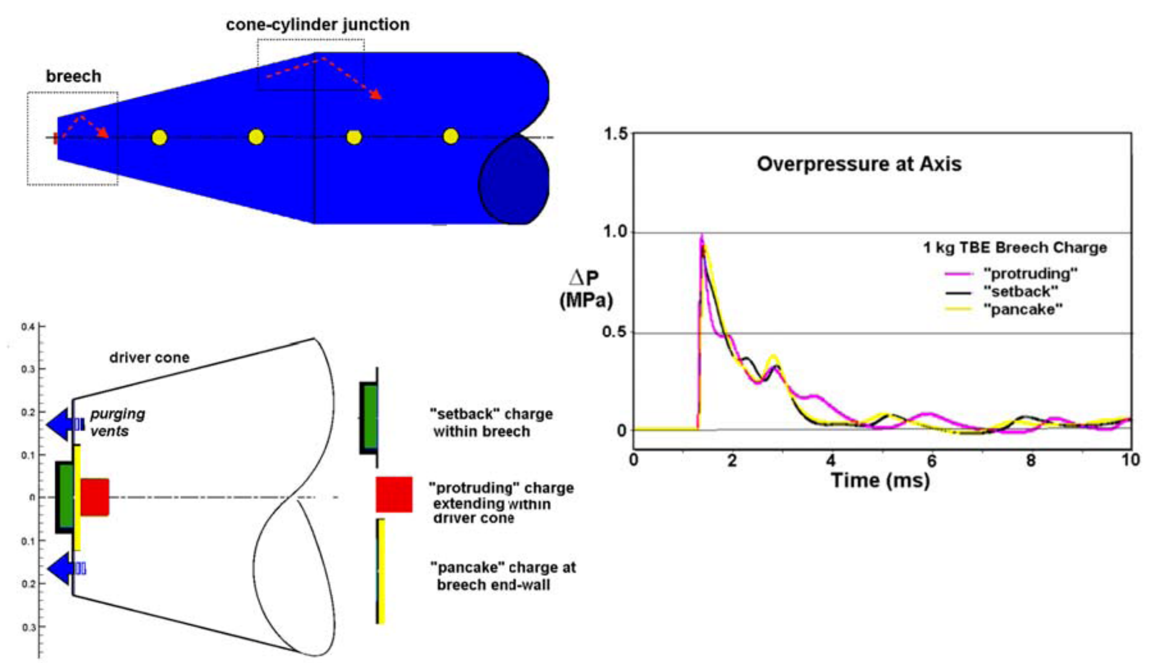

Figure 10. CFD modeling of the effect of blast generation down the tube from various 1kg LE charge configurations. Some transverse reflections develop from the initial radial expansion of the blast at the breech end as well as from the downstream blast impinging on the junction of the conical driver and main cylindrical tube. All charges developed similar blast profiles. Transverse reflections which are exaggerated along the tube axis as shown here can be largely eliminated by cowling liners at reflection interfaces.

developed which amplifies as it implodes to the Tube axis at about the 4m location. In practice, the use of simple expanded-metal cowlings, grills, and liners at wall reflection interfaces can be installed to greatly mitigate these reflections.

As a rough guide, the blast generated from a LE driver charge will simulate that from a spherically expanding free-field charge of about 65-times its mass during the early expansion through the conical driver section. Thereafter, the blast propagates at nearly constant impulse while the duration extends and peak amplitude decays as previously described for constant-area shock-tubes.

Significant control of the blast profile developed down the Tube can be achieved by variations of the basic LE breech geometry. Control of the negative phase, duration, and in fact simulation of the secondary shock can be achieved by means of an extension tube from the back of the breech with adjustable venting. Alternatively, the current venting ports from the breech end, which are usually activated for purging detonation-product gases from the driver post-shot, can be left open during firing. When full-reflection panel targets are mounted to block the end of the Tube, open ports at the driver end eliminate the blast repeatedly reverberating the length of the Tube and affecting target response. Especially when combined with the other upgrade modifications, such as a relocatable test table to be described, simple variations of the LE breech configuration offers means for both extending the range of P-I test conditions and wave-shaping.

4.2 Relocatable Target-Mounting Station

One of the simplest means to adjust blast conditions for diffraction targets being tested within the Tube is to construct a relocatable test station by which the position of a test article can be varied from very close to the driver to near the end of the Tube at 44m. For any given driver charge, whether LE or FAE, positions closer to the driver will clearly yield much stronger blast and shorter durations. Targets can be subjected to blast conditions approximating those at the edge of the fireball from an HE event (~ 1MPa and 5ms duration) providing these are not too large, which should have a presented area less than $0.25m^2$. As previously described, keeping a fixed driver charge and varying target position allows tracking of a 'constant-impulse' profile across its P-I response domain. Therefore, between variance of the charge size and the position of the test station, a broad domain of the article's P-I response can be assessed.

Depending on the nature of the target being tested, the relocatable test station may be as simple as a transverse bar across the Tube from which a target may be suspended, or a more traditional test table. Preliminary calculations and experience drawn from the design and performance of similar blast test tables show that a heavy-wall design such as sketched in Fig. 11 will be adequate to secure targets in severe near-field blast conditions close to the driver. Some manner of bolt-hole template would be required over the surface plate of this table for securing targets. A cavity within the table, which can be accessed by a flip-down back plate as shown in the sketch, could be used for self-contained recorders if running of cables from the target out through the Tube wall was not desirable or feasible.

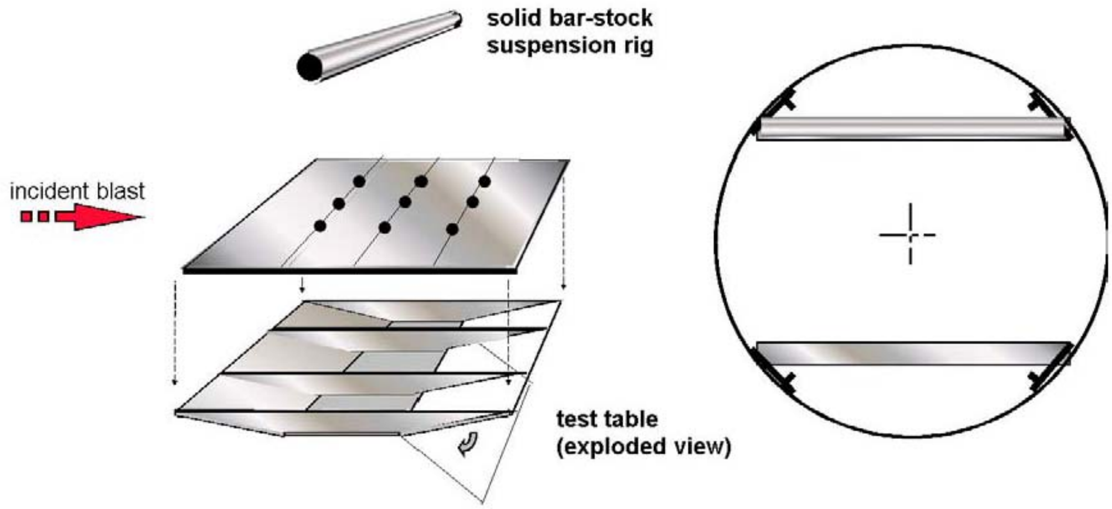

Figure. 11. Design sketch for a heavy-plate relocatable test table or suspension bar capable of securing diffraction targets through a range of test stations along the Tube length, including close to the fireball conditions of the driver. Flanges along the side of the table allow securing these target mounting stations by bolts to rails welded along the internal sides of the Tube.

The current fixed test-table station at 30m from the driver is very strongly secured through the Tube wall to a massive concrete foundation. For some target structures which may transmit excessive forces to their mounting fixture, use of this primary test station may be required and, as will be described later, has several features not available to the relocatable target mounts.

4.3 End-Tube Extension/Expansion and Target Reaction Frame

Installation of a special extension/expansion section to the end of the Tube will be necessary to meet a number of important target testing requirements. Foremost of these requirements is the ability to test full-scale structural panel or wall sections typical of civil and industrial construction to the level of one story under strong blast conditions. As such, the underlying feature of the Tube extension is the expansion of the test section from the current 1.8m round end-section to a square cross-section of 2.5m a side.

Since semi-hardened structures such as reinforced brickwork or blast-hardened window designs with anchoring may be tested, a substantial mounting framework as well as a reaction foundation are required. The dimensions of 2.5m-square, possibly extending to 3m-square, is the practical upper bound for testing of semi-hardened panels at the Blast Tube facility. Any vertically mounted panel targets which are much larger or stronger, such as reinforced concrete slab, would require a prohibitively large and expensive reaction frame and foundation. The Heavy Panel Blast Test-Bed near the HOB Site at DRDC Suffield was designed for testing of large hardened panel structures; it uses a height-of-burst charge over a heavily reinforced concrete basement foundation to secure target panels of up to 4m x 3m. A 1m crawl-space beneath the panel allows for panel deflection and installation of response instrumentation including high-speed photography.

The fabrication of a special (and likely expensive) transition section from circular to square for this extension of the Blast Tube should not be required. As shown in Fig.12, a ‘pyramidal horn’ extension of square cross-section can be fit directly onto the end-flange of the current circular tube. This pyramidal horn would therefore begin with a 1.8m square cross-section expanding to 2.5m square cross-section in 5m to the panel-mount reaction frame. Whereas the blast wave emerging from the end of the 1.8m circular section will diffract and reflect somewhat in the transition to the square cross-section, these transverse reflections can be mitigated by simple triangular filler plates fit into the corners of the square cross-section for a distance of perhaps 1m. Expanded-metal cowling at reflective junctures is also effective to diffuse transverse waves through this transition. To avoid high stresses along the corners of this structure, the four panels forming the walls of the horn should not be welded or hard-fastened along their edges, but have fasteners allowing some flexure and in fact slight separation under extreme reflected loading conditions.

An extremely rigid yet versatile mounting frame is required for securing varied types of target panels which will effectively close off the end of the pyramidal horn extension. However this mounting framework should be structurally separate from the Blast Tube extension and mounted on a roll-away railcar. Note that the target-mounting railcar should also be designed to accommodate possible room enclosures behind target panels. When diffraction targets are mounted within the Tube (as distinct from panel, wall, or room structures blocking the end of the Tube), the target-mounting frame has the important role of controlling effects of rarefactions propagating from the open end of the Blast Tube. Particularly for diffraction targets mounted close to the end of the current Tube, there will be very strong adverse loading effects due to the arrival of the rarefaction or reflected shock-wave system arising from the end condition. A simple grill-work providing a partly-vented, partly-reflected end condition will greatly reduce this problem.

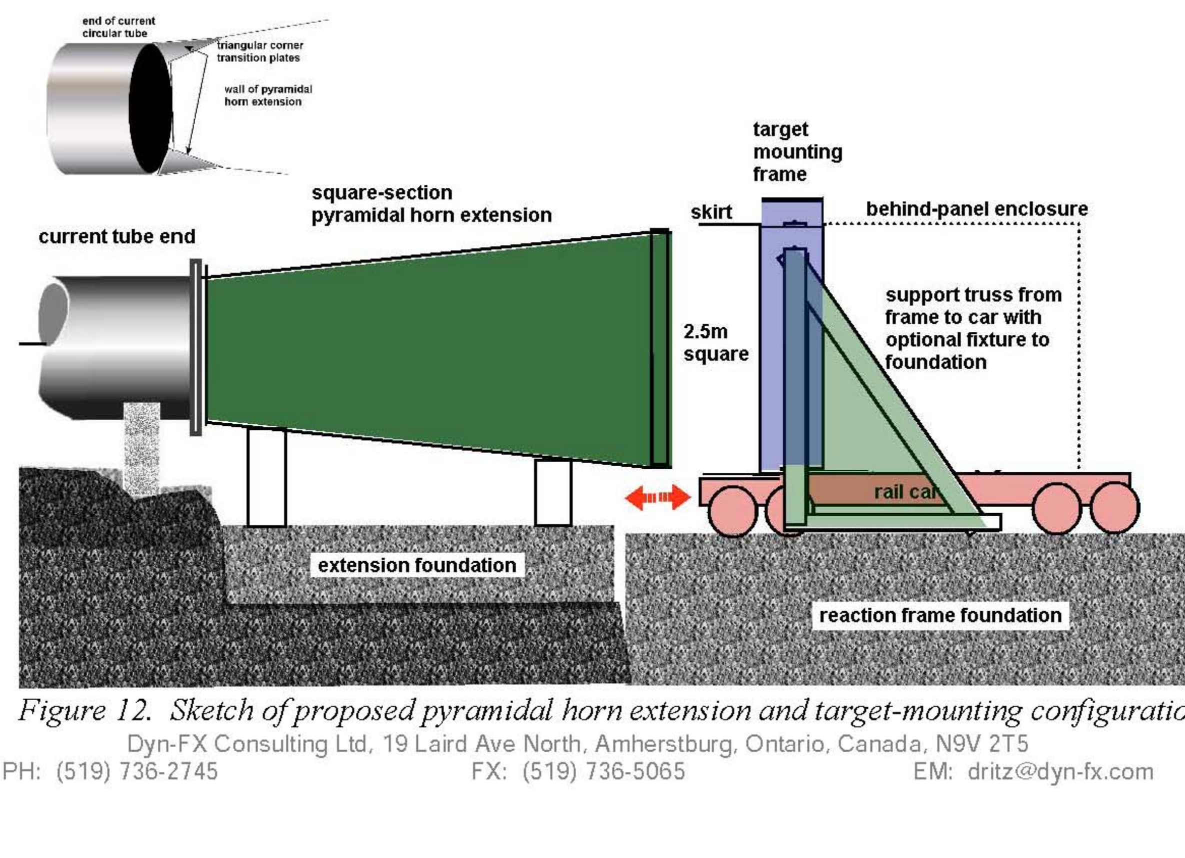

Figure 12. Sketch of proposed pyramidal horn extension and target-mounting configuration.

Rail-mounting of the entire target-frame is required not only to allow its complete pull-back for mounting of target panels and their instrumentation (as well as giving access to the Blast Tube interior for other reasons), but to serve as the best means to absorb the full reflected impulse imparted to a panel target. A heavily ballasted railcar will serve as the most effective inertial mount in itself for many targets, however for the most resilient target panels this car can be secured to the massive concrete foundation underlying the target-platform foundation. The heavily ballasted railcar allows enormous reflected loading to be imparted as a minor, late-time rolling action rather than inducing severe shock-stresses had the frame been rigidly fixed to the foundation without an inertial mass. The allowance for a behind-panel enclosure is important not only for studies of blast ingress into rooms, but to allow for an instrumented area to assess deflection, wall ejecta, or debris-throw [12-14]. Such an enclosure will also will serve as a practical and convenient staging area for preparing and installing target instrumentation including behind-panel high-speed cameras. If possible the railcar should be equipped with an overhead crane and hoists/pulls to move the railcar itself along its foundation, or to upload and install targets.

An important feature which can be included in the design of the extension/expansion section is the capacity to introduce controlled side-venting. Due to the nature of blast propagation in a constant-area tube, load durations at the end of the Tube will often be too long for simulation of many conventional blast threats even for the smallest driver charges. Adjustable side-venting near the target-end offers a means to control load duration yet maintain reasonable high peak load pressures. Such venting can be achieved by several methods having various degrees of complexity, cost, and effectiveness. In the simplest option, adjustable side-venting can be achieved by a pattern of holes or slots through the walls of the extension which can be closed-off or opened by a sliding cover plate. However, a louvered arrangement such as sketched in Fig. 13, in particular having the slots canted inwards as shown, offers some advantage in deflecting some shock-front energy back inwards to the flow while introducing rarefactions from behind the blast front. Therefore, such louvers allow reduction of the net impulse and duration of the wave while minimizing reduction of the blast front.

Extensive blast CFD modeling was conducted to assess the effects of the many potential variables of venting configurations. As shown in Fig. 13, this modeling suggests that with a carefully designed venting configuration a nearly ten-fold reduction in impulse may be possible with only slight weakening of the peak reflected loading. This technique would allow traversing of a target's P-I response domain at constant 'P' with a simple louver adjustment between shots while keeping the driver charge and target station fixed. Therefore, combined with adjustment of the driver charge size, it will be possible to map a target's response through a large area of the P-I domain quite quickly and efficiently. For the case of a target-panel blocking the end of the Tube, side-venting offers also offers a practical advantage of allowing ingress of make-up air for the purging of detonation products from the driver post-shot.

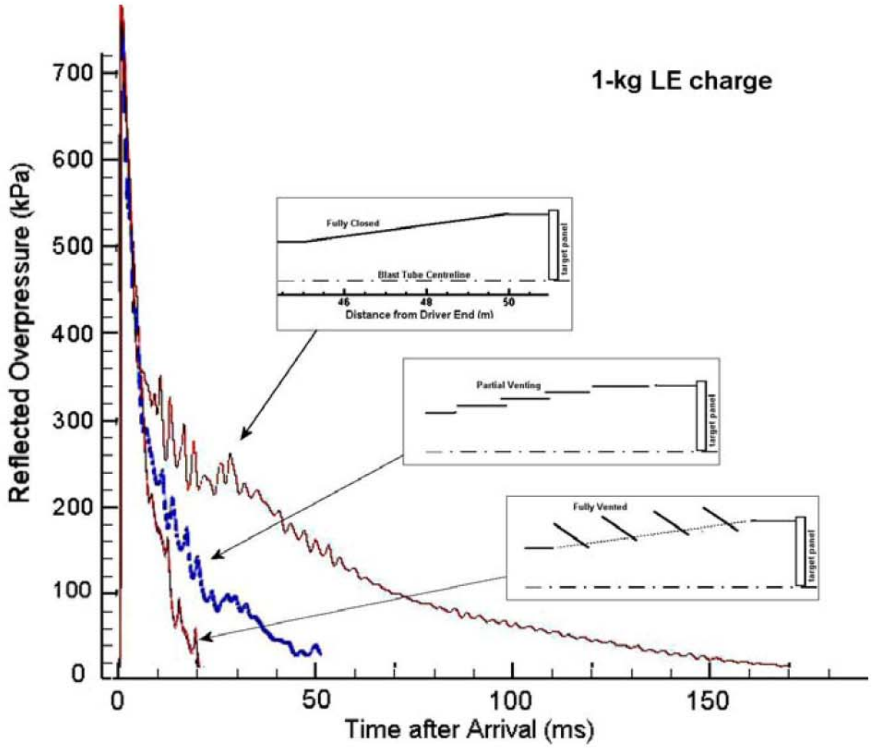

Figure 13. Computational modeling results for the effectiveness of louvered side-venting to control reflected load impulse and duration for panel targets mounted at the Blast Tube end-frame while keeping nearly constant peak overpressure for a given driver charge.

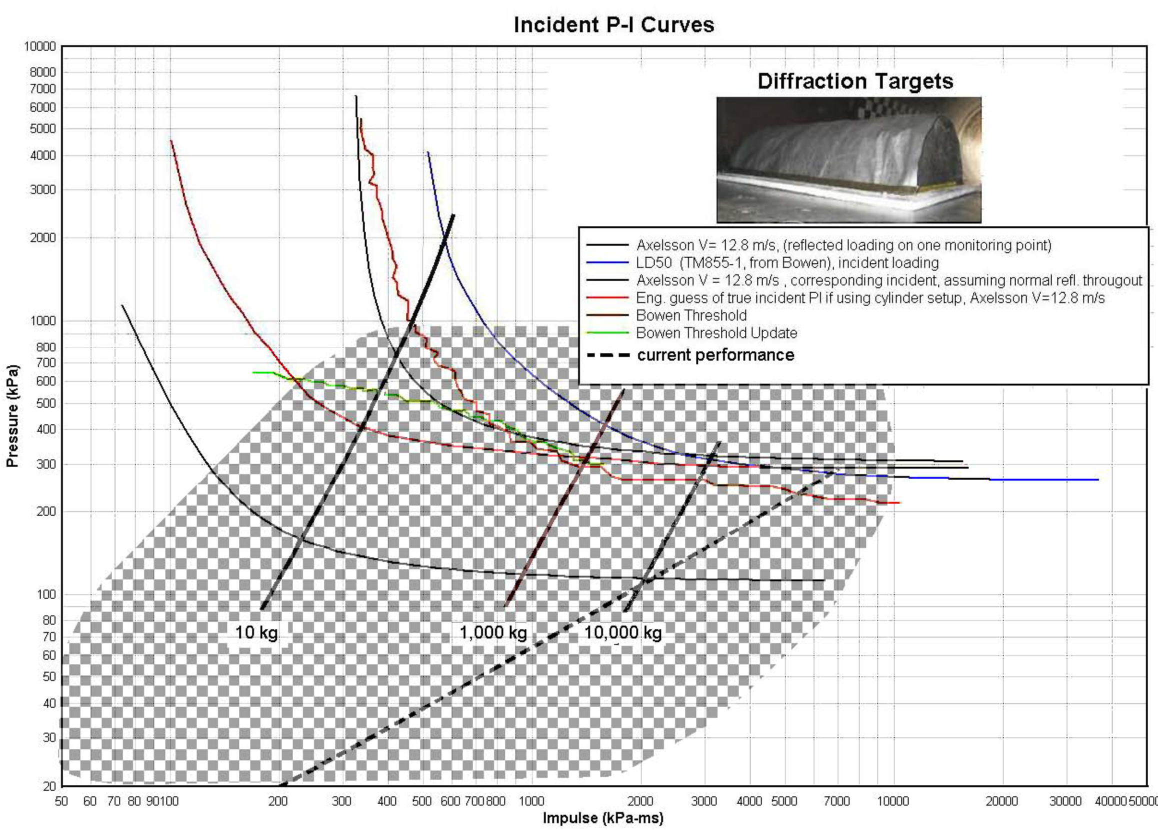

Figure 14. Potential extended Blast Tube performance domain for diffraction targets with new LE driver and relocatable test station.

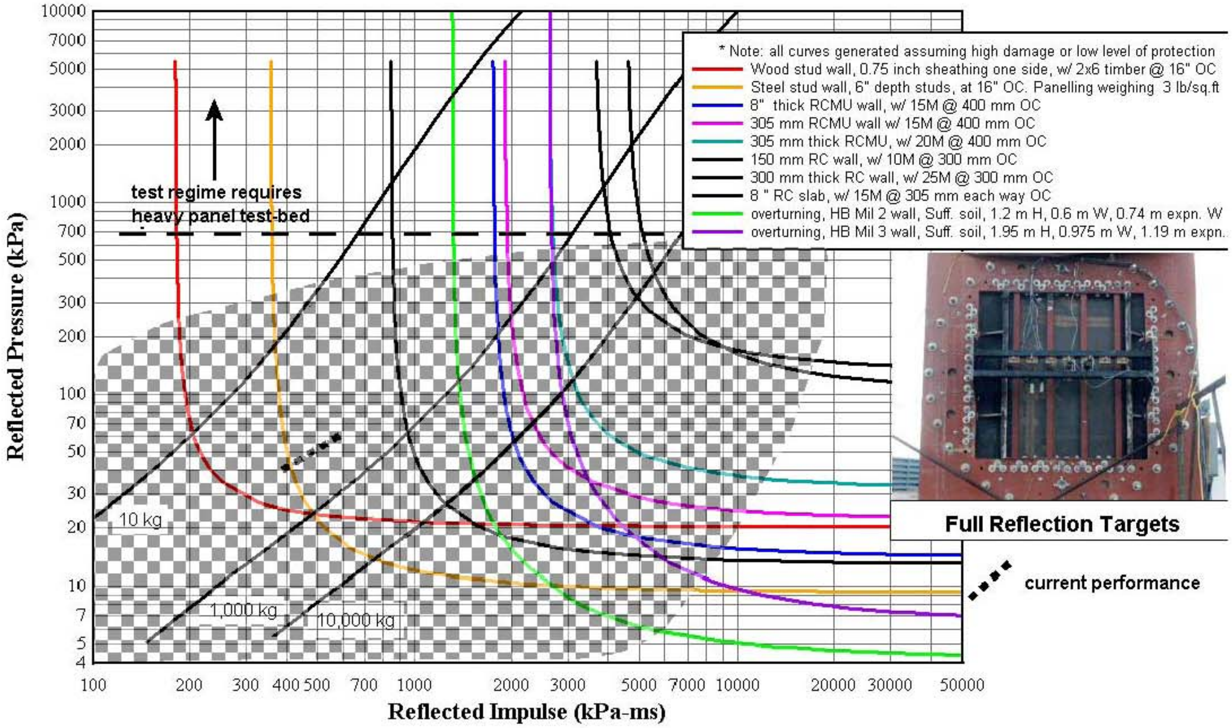

Figure 15. Potential extended Blast Tube performance domain for full-reflection panel targets based on reflected loading at end of the Tube.

5. Detailed Design and Validation

Although the aforementioned concepts are known to be viable from theory, computational studies, or successful variants used at other facilities, these must clearly be further developed and validated before proceeding with any full-scale construction. It is strongly recommended that the advanced detailed development be undertaken through use of working scale-model shock-tube prototypes as well as blast CFD modelling. Most concepts, such as the side-venting end-section to adjust reflected impulse loading, can be quickly developed and refined at the model-scale using laboratory air-driven shock tubes. Allied agencies with interest in these concepts have volunteered use of their shock-tubes for this purpose. Blast CFD modelling can be used to validate both the scale-model results and, by extension, the performance of the actual full-scale layout. Secondly, blast CFD modeling should be used to design the details of the LE driver configuration and panel mounting frame for the end-section. The design of the Tube extension and target-mounting frame will also likely require computational structural dynamics (CSD) modelling with an explicit finite-element code such as LS-DYNA® or AUTODYN®.

6. Refurbishments

Beyond extending the P-I range of the Blast Tube facility by introducing modifications and new constructions, two core operational aspects of the current facility require significant refurbishment if not entire revamping.

6.1 Gas Flow Control and Monitoring System

The system controlling the flowing of explosive gases, charging of reservoirs, and dispersal of gaseous fuel within the driver for detonation is over 20 years old. The ease-of-use and reliability of the gas metering system is central to efficient use of staff and generation of high-quality and repeatable blast profiles. A technical review of the entire fuel-flow and firing setup is required with the prospect that revamping of the system may be required. It is recommended that the timing of any such overhaul of the FAE system be synchronized with the commissioning of the optional LE driver system such that the facility can continue to be operational for target studies.

6.2 30m Test Table Station

The primary test station for diffraction targets is located at the nominal 30m location from the breech end. The station has a specially designed and very strong test table which penetrates the sides of the Tube such that its support does not present any obstruction within the working section. Instrumentation conduits run from within a cavity in the table through the Tube wall and hence are fully protected from blast interference. The table is bolted externally to a massive concrete foundation which also serves as a cradle support for the Tube itself at that location. In addition to the robust and effective table design, the station is also outfitted with camera ports and increased concentration of wall static pressure ports.

This test station was originally designed with the capability to have a hinged 'clam-shell' access directly from the target preparation bay of the Bldg. 48 enclosure. The table is also equipped with an overhead crane on a rail for installing heavier targets. For unclear reasons the clam-shell access was never activated and was instead fully welded shut. Access to the test table or the Tube itself must be made either through a forward man-hole access close towards the driver, or by exiting Bldg. 148 to ambient weather conditions, entering the open end of the Tube, and returning inside the Tube to the test table location. Mounting targets at the table is particularly laborious and cumbersome since all materials have to be hauled in from the open end of the Tube which is also exposed to the weather.

As shown in Fig. 16, important refurbishments to the 30m test table station include the activation of the clam-shell or similar access directly from the target assembly bay of Bldg. 148. Furthermore, the test table surface, having been over-drilled repeatedly for customized target mountings, must be replaced with a new plate with a prescribed bolt-hole pattern to which all targets need to be prepared. The new table-top should also be re-designed to have a central rotating section such that a target secured there can be re-oriented to the blast without having to reconfigure and re-bolt the test article.

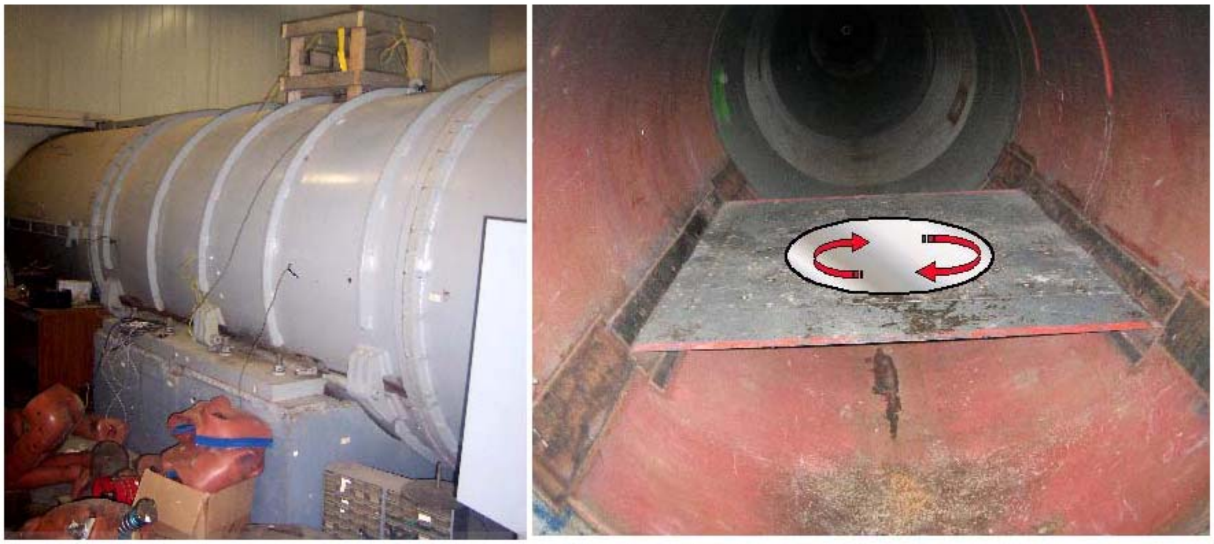

Figure 16. Refurbishments to the primary 30m Test Station include means for direct access from the Bldg. 148 target assembly bay. The current table-top should be replaced with one having a prescribed target bolt pattern and a central disc section allowing rotation of the target with respect to the blast incidence without the need to disconnect target fixtures or instrumentation.

7. Conclusions

A feasibility study has been completed for concepts to upgrade the performance of the DRDC Suffield Blast Tube facility to meet testing requirements of current research programs concerning blast protection. By means of straightforward modifications, the operational range can be extended to a much broader domain in terms of peak blast pressure and impulse as well as its capacity to better mount full-scale responding targets. Blast conditions equivalent to those from several kilograms to thousands of kilograms free-field high-explosive (HE) can be simulated. This extended capability can be achieved by the following modifications which can be implemented separately in phases:

- Installation of an optional breech insert for low-VOD explosive (LE) charges. LE charges produce stronger blast at lower durations than the current FAE driver, yet do not have the storage/handling difficulties or damage potential to the current driver as HE driver charges.
- Installation of a relocatable test table which will allow testing of $0.25m^2$ diffraction targets at conditions simulating those near the edge of an HE fireball (1MPa x 5ms) to low amplitude deflagration events (1kPa x 100ms)
- Construction of an extension/expansion section for the current end of the Tube having a reaction-frame foundation to allow mounting of full-scale structural wall/panel segments 2.5m-square, as well as room enclosures.
- Refurbishment of the current main 30m Test Station including activation of the ‘clam-shell’ access and resurfacing of the test table for improved target mounting.
- Upgrade and refurbishment of the current FAE fuel-flow control and firing system, including the redesign of the fuel dispersal rig of the current FAE driver to allow its extraction for staging of LE firings.

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Upgrade proposals are presented for the DRDC Suffield Blast Tube facility designed to extend its testing range and capabilities for conducting studies of structural response and injury from blast. By means of straightforward modifications, the facility's operational Pressure-Impulse (P-I) envelope can be greatly extended as well as its capacity to test full-scale responding targets. Blast conditions equivalent to those from charges of several kilograms of high-explosive to small tactical nuclear devices (0.25KT) can be simulated. This extended capability can be achieved by the following modifications which can be implemented independently in phases if necessary:

- Installation of an optional breech insert for condensed low-explosive (LE) charges
- Installation of a relocatable test table
- Construction of an extension/expansion section for the current end of the Tube
- Refurbishment of the current main 30m Test Station
- Upgrade and refurbishment of the current FAE fuel-flow control and firing system

Advanced conceptual designs for the upgrades are presented, and the efficacy of the proposals in extending the P-I range is demonstrated by blast CFD modeling. For each upgrade proposal, a more detailed engineering study will be required prior to proceeding with fabrication or re-construction; sub-scale shock-tube testing and more detailed computational modelling should be applied for this purpose. The upgraded facility offers much lower cost, higher reproducibility and control of variables, higher safety, and freer scheduling than explosive field trials. The capabilities offered by this facility will be unique in Canada and amongst the most efficient for this scale of testing in the world.

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